Season-Long Releases of Partially Sterile Males for Control of Codling Moth (Lepidoptera: Tortricidae) in Washington Apples

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ABSTRACT Season-long field studies were conducted in Washington apple orchards that compared the following: (1) twice per week releases of partially sterile codling moths, *Cydia pomonella* (L.), treated with either 100 or 250 Gy, and (2) combinations of mating disruption plus the release of partially sterile (100 Gy) codling moths, to control wild codling moth populations. No significant differences in the level of fruit damage at either midseason or harvest were found between any of the treatments, or between the treatments and the inside controls. Damage in all plots was <0.1%. In both studies, trap data suggest that the movement of the 100 Gy-treated moths into the other treatments and the inside controls may have masked treatment effects. However, fruit damage was significantly lower in all treatment plots when compared with control plots located outside of the treatment areas. Results indicated that the release of partially sterile male (and fully sterile female) codling moths does not result in increased fruit injury and that the lower dose of radiation used to partially sterilize males results in insects that are more active, disperse greater distances and are generally more competitive.

KEY WORDS *Cydia pomonella*, inherited sterility, fruit damage, apple

THE CODLING MOTH Areawide Management Program (CAMP) was conducted in the western United States (Washington, Oregon, California) from 1995 to 1999, based primarily on the use of mating disruption for control of codling moth, *Cydia pomonella* (L.), the key pest of apples (Calkins et al. 2000). Different CAMP sites combined additional pest management tactics with mating disruption, including biological control, application of oils and bacterial toxins, and the release of sterile codling moths (Calkins 1998, Calkins et al. 2000). Since its inception, the Lake Osoyoos CAMP site in Oroville, WA, used a combination of mating disruption and releases of sterile moths provided by the Canadian codling moth mass-rearing facility located in Osoyoos, British Columbia. In 1995 and 1996, mating disruption was applied at the rate of 1,000 dispensers per hectare in Lake Osoyoos CAMP orchards and sterile moths were released during the last 10 wk of the growing season. In 1997–1999 mating disruption dispensers were again used at the same rate, however, sterile moths were released for the entire (20 wk) growing season. Results at Lake Osoyoos suggested that the release of sterile moths is complimentary to mating disruption. For example, codling moth damage at harvest in 1997 was reported to be 0.06%, down from 2.2% in 1995. Equally as important, the number of organophosphate spray applications for control of codling moth in Lake Osoyoos orchards was reduced from an average of 2.2 per season in 1995, to 0.75 in 1996, 0.17 in 1997 and 0.07 in 1999 (Calkins et al. 2000).

In British Columbia, Canada, the release of sterile moths for codling moth eradication (SIR Program) was initiated in 1994 (Dyck et al. 1993). In 1997 and 1998 the program maintained a production of 14–15 million codling moths per week that were released into ≈3,250 ha of apples and pears (L. Tomlin, SIR Program, personal communication). At the end of 1997, the program reported that the number of orchards within the treatment area with 0% codling moth damage at harvest was 89.9% of 427 blocks sampled. In 1998, this number was 86.2% of 399 orchards sampled (SIR Program, unpublished data).

Recently, Bloem et al. (1999a, 1999b) discussed the advantages of incorporating inherited sterility into codling moth sterile release programs. Inherited sterility (or F_1 sterility) differs from the sterile insect technique in that the dose of gamma radiation is adjusted so that released females are completely sterile but males are only partially sterile (LaChance 1985). When partially sterile males mate with wild females the radiation-induced deleterious effects are inherited for one or more generations (North 1975). In other lepidopteran pests, releasing partially sterile insects has been shown to offer greater suppressive potential because of increased mating competitiveness (Carpenter et al. 1989) and the build-up or production of

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sterile insects in the field (Carpenter and Layton 1993).

Bloem et al. (1999a) showed that the fertility of codling moth males and females was significantly lowered when treated with increasing doses of gamma radiation. The minimum dose at which treated females were found to be 100% sterile was 100 Gy, which is much lower than previously suggested (Fossati et al. 1971, Proverbs et al. 1978). At this dose (100 Gy) codling moth males are still 50% fertile. Bloem et al. (1999a) also showed that fruit damage was significantly reduced when partially sterile moths were released in conjunction with known numbers of fertile moths at a 10:1 overflooding ratio inside large field-cages containing a single apple tree. Furthermore, in release-recapture tests Bloem et al. (1999b) showed that significantly more codling moth males were recaptured in traps when lower doses of radiation were used. These authors also showed that lowering the dose of gamma radiation increased male codling moth mating competitiveness in the field.

Given the positive results of CAMP in the Pacific Northwest (Calkins 1998), the SIR Program in Canada (Bloem and Bloem 2000), and encouraging data from previous experiments (Bloem et al. 1999a, 1999b), we felt that continued work on codling moth F_1 sterility was warranted. The increased competitiveness of partially sterile rather than fully sterile codling moths could translate into effective pest suppression being achieved faster or by releasing fewer insects (Knipling 1970, Carpenter 2000). Here we present the results of a series of season-long field experiments conducted in Washington apple orchards in an effort to examine the degree of control realized by twice per week releases of partially sterile codling moths (treated with either 100 or 250 Gy) or by combining releases of partially sterile (100 Gy) codling moths with commercially available mating disruption (at full and half rates).

Materials and Methods

Season-Long Releases of Partially Sterile Codling Moths. *Kernan Study Site.* The experiment was conducted during 1998 in a large (≈30.5 ha) mixed 'Golden Delicious' (88%) and 'Red Delicious' (12%) apple orchard on the west side of Lake Osoyoos above Oroville, WA. Tree spacing was 3.65 by 6.10 m, with ≈500 trees per hectare and an average tree height of 4.50 m. Before 1998, this site was managed conventionally using four to five cover sprays of azinphosmethyl for control of codling moth per growing season (S. B., unpublished data). The orchard had a history of moderate codling moth pressure with peak first generation trap counts of 3–6 moths/trap/week and 1–2% codling moth damage at harvest (S.B., unpublished data). Two large blocks within the orchard were each divided into three plots ranging in size from 1.04 to 1.47 ha. The large blocks were separated from each other by a newly replanted one ha field and a road (actual distance was >150 m). Individual plots within these blocks were separated from each other by ≈30 m. All plots within a block received the same treatment. Additional separation of the plots was not possible because the owner required that the remainder of the orchard be managed conventionally. Three additional one ha blocks were identified in the Kernan site and used as (inside) controls. The control blocks were separated from one another and from the treatment blocks by no <150 m.

Insects. Standard colony codling moths purchased from the SIR Program mass-rearing facility in Osoyoos, British Columbia, Canada, were used in this experiment. All laboratory-reared moths are marked internally by the addition of Calco-Red dye to the larval diet. Newly emerged (<24 h old) adult moths were divided into two groups and marked with a distinguishing fluorescent dust (Day-Glo Color, Cleveland, OH) as described in Bloem et al. (1998). All insect handling occurred inside a cold room (0–2°C) at the SIR facility. Once colored, the adult moths were packaged into petri dishes (23 g moths/dish) and treated with either 100 Gy or 250 Gy of gamma radiation from a Cobalt^{60} source (Gammacell 220; Nordion, Canada; dose rate of ≈125 Gy/min). At the selected doses female codling moths were 100% sterile and male moths were 50% and 80% sterile, respectively (Bloem et al. 1999a). Treated moths were held at 0–2°C until field release.

Field Release. Moths were transported to the field inside a small cooler. The moths were released twice per week for 21 wk, from 18 April to 12 September 1998, along marked lanes ≈30 m apart in the six plots. The three plots in the first block received moths treated at 100 Gy and the three plots in the second block received moths treated at 250 Gy. Releases were made in the morning (≈1100 hours [PST]) using a moth dispensing unit mounted on the front of an all-terrain vehicle, which was similar to those used by the SIR Program and slightly modified from that described in McMechan and Proverbs (1972). This device gently blew the moths into the vegetation underneath the trees as the vehicle was driven through the plots. Moths were released at the rate of 46 g of moths per hectare per week (≈1,533 adults, mean weight = 30 mg, sex ratio 1:1). Releases were always made first in plots receiving moths treated with 100 Gy. The moth dispensing unit was then cleaned with a damp cloth and dried before releases of 250 Gy treated moths were made to avoid fluorescent color contamination.

Monitoring. Pheromone-baited (1 mg codlemone) wing traps (Scenturion, Clinton, WA) were used to monitor the movement of the released moths. Traps were spaced evenly throughout the Kernan site at a density of one per ha and hung in the upper one-third of the tree canopy (mean trap height = 3.0 m). Sticky inserts were replaced once per week and pheromone lures were changed every three weeks for the duration of the study. In the laboratory, inserts were examined under UV light to identify the color, and thus the treatment, of the trapped moths. The abdomens of all nonfluorescent trapped moths were squashed to confirm whether they were wild or laboratory-reared as described by Bloem and Bloem (2000).

Table 1. A description of the tactics used in 1998 to control *Cydia pomonella* (CM) in the various treatment, control and comparison blocks used in these experiments

Plot	Chemical treatment	Biological treatment
Kernan Orchard		
100 Gy	1 application of azinphosmethyl	100 Gy treated moths released @ ≈766 moths/ha 2X/wk
250 Gy	1 application of azinphosmethyl	250 Gy treated moths released @ ≈766 moths/ha 2X/wk
Inside control	2 applications of azinphosmethyl	
Outside control	6+ applications of azinphosmethyl	
Gold Hill Orchard		
Treatment A = MD		Isomate C+ @ 1,000 dispensers/ha
Treatment B = CM		100 Gy treated moths released @ ≈766 moths/ha 2X/wk
Treatment C = MD + CM		Combination of Treatments A + B
Treatment D = ½MD + ½CM		Isomate C+ @ 500 dispensers/ha + 100 Gy treated moths released @ ≈383 moths/ha 2X/wk
Inside control	2 applications of azinphosmethyl	
Lake Osoyoos CAMP Orchards		
CAMP original		Isomate C+ @ 1,000 dispensers/ha + 250 Gy treated moths released @ ≈766 moths/ha 2X/wk
CAMP 98 Expansion	Avg. 1.72 applications of azinphosmethyl	Isomate C+ @ 1,000 dispensers/ha + 250 Gy treated moths released @ ≈766 moths/ha 2X/wk
CAMP control plots	Avg. 3.60 applications of azinphosmethyl	

Fruit Damage. To ascertain the degree of control provided by the released moths, fruit sampling was conducted in release and (inside) control plots at midseason (24–28 June 1998) and at harvest (25 August–11 September 1998). Twenty-five Golden Delicious trees from a 5 × 5 tree square located in the middle of each plot were sampled. One hundred whole fruit were examined per tree, 60 from the top one-half and 40 from the bottom one-half of each tree, for a total of 2,500 fruit per plot. An equal number of fruit from all tree quadrants (N, S, E, and W) was examined. Fruit sampling also was conducted in orchard blocks managed conventionally by the same owner that were isolated from the experimental site by a deep ravine and a distance of >500 m, to serve as an outside control.

F_1 Larvae. To ascertain whether the partially sterile released moths were producing F_1 larvae that might contribute to fruit injury, tree banding was conducted in both release and (inside) control plots at midseason (7 June–15 July 1998) and at harvest (10 August–10 September 1998). Corrugated cardboard bands (C-flute; 12 cm wide) were placed around the trunks of the same trees (from a 5 × 5 tree square located in the middle of each plot) that were used for fruit sampling. Tree bands were removed and examined in the laboratory for the presence of larvae.

Comparison Blocks. In addition to data from the inside and outside control plots, fruit damage data for midseason and harvest were obtained from the Lake Osoyoos CAMP site (Richardson et al. 1999) to serve as additional comparisons to the results obtained in our experiments. Data were provided for three CAMP 'treatments' (Table 1): (1) Original CAMP orchards, which had been part of the project since 1995; (2) CAMP 98 Expansion orchards, which were contiguous with the original CAMP orchards but only entered the project in 1998; and (3) CAMP Control orchards, which were near Oroville, WA, but were managed conventionally and were outside of the CAMP treatment area.

Releases of Partially Sterile Codling Moths in Combination with Mating Disruption. *Gold Hill Study Site.* A large (≈27 ha) mixed Golden Delicious (75%) and Red Delicious (25%) apple orchard on the west side of Lake Osoyoos in Oroville, WA, was used for this experiment. Tree spacing was 4.60 by 5.50 m, with ≈450 trees per ha and an average tree height of 3.25 m. The orchard had a history of low codling moth pressure. In 1997, two azinphosmethyl cover sprays were used against codling moth and fruit damage at harvest was < 1.0% (S. B., unpublished data). Fifteen one ha blocks were identified within this study site, providing for three replicates of four treatments and one control. Spacing between all treatment blocks was ≥15 m. However, as a requirement by the orchardist the three 1-ha blocks used as controls were separated from the treatment blocks by ≥30 m. The same outside control (from the Kernan site) was used for this experiment. The outside control was separated from the treatment blocks by ≥800 m. The following treatments (see Table 1) were randomly assigned to the blocks: treatment A − mating disruption (MD), applied at the standard rate of 1,000 pheromone dispensers per hectare; treatment B − codling moths (CM) treated with 100 Gy and released at the rate of 46 g of moths per hectare per week; treatment C − mating disruption + codling moths (MD+CM); and treatment D − ½MD + ½CM.

Pheromone dispensers (codlemone, Isomate C+, Pacific Biocontrol, Vancouver, WA) were tied manually to modified plastic bread clips (Series WT, Kwik-Lok, Yakima, WA) and attached to tree branches (using extendible poles) in the top one-third of the tree canopy (mean height = 3 m) at the above-mentioned rates on 11–12 April 1998. Moth releases were made twice per week along marked release lanes as described for the Kernan site from 18 April to 12 September 1998.

Wing traps (Scenturion, Clinton, WA) baited with standard (1 mg) or high-load (10 mg) codlemone lures were used to monitor the movement of the released codling moths. Plots treated with mating disruption alone (treatment A) were monitored with 10-mg traps only. In plots receiving releases of codling moths (treatments B–D), two traps, one with each type of lure (1 and 10 mg), were hung per plot ≈15 m from one another. The use of traps with both types of lures in plots treated only with partially sterile moths (treatment B) helped determine whether pheromone drift (from treatments A, C, and D) was contaminating treatment B (1-mg traps capture significantly fewer moths in the presence of mating disruption). Inside control plots were monitored with 1-mg traps. Recapture of partially sterile moths within treatment plots were compared using 10-mg traps. In all cases, traps were placed in the upper one-third of the tree canopy (mean trap height = 2.5 m). Traps were serviced and insects identified as previously described.

To ascertain the degree of control provided by the treatments, fruit sampling was conducted at midseason (24–28 June 1998) and at harvest (25 August–11 September 1998), in a 5 × 5 tree square (Golden Delicious trees) located in the middle of each plot as previously described. As in our first experiment, the data collected were compared with damage data provided by the Lake Osoyoos CAMP. To ascertain whether the partially sterile released moths were producing F_1 larvae, tree banding was conducted as described for the Kernan site.

Statistical Analyses. Codling moth trap (10 mg lure) captures from the Gold Hill orchard plots receiving treatments A, B, C, and D were subjected to analysis of variance (ANOVA) and the means were separated using Waller-Ducan *K*-ratio *t*-test (PROC GLM, SAS Institute 1989). In both experiments and for data from the Lake Osoyoos CAMP site, percent codling moth damage at midseason and harvest was calculated by dividing the number of damaged fruit found per plot by the total number sampled. Damage data were tested for normality using the Kolmogorov-Smirnov statistic (PROC UNIVARIATE, SAS Institute 1989). These data were not normally distributed ($D = 0.356$, $P < 0.01$ for the Kernan site; $D = 0.361$, $P < 0.01$ for the Gold Hill site) and arcsine transformation did not improve normality ($D = 0.283$, $P < 0.01$ for the Kernan site; $D = 0.270$, $P < 0.01$ for the Gold Hill site). Rank means of the percent damage were subjected to a nonparametric ANOVA (PROC NPAR1WAY, SAS Institute 1989). In both experimental sites (Kernan and Gold Hill) the treatment plot layouts were constrained by the desire of the orchardists to keep the conventionally controlled areas of the orchards consolidated. These practical limitations required all treatment plots to be in a single contiguous block within each orchard. Due to the largeness of scale and the restrictions imposed on the experimental design by the orchardists, field experiments like the ones conducted in these studies must rely on replications that are defined more broadly than the strict statistical definition. Nevertheless, these analyses are useful in providing a measure of confidence in the careful interpretation of these data.

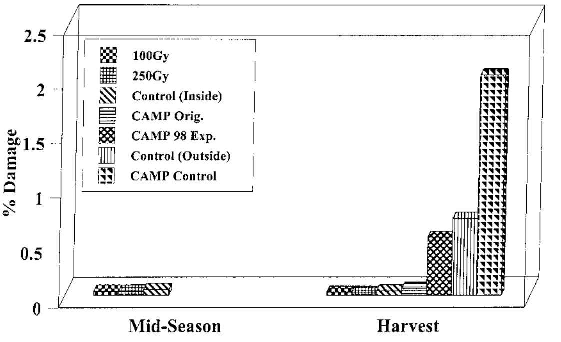

Fig. 1. Percent damage by codling moth, *Cydia pomonella,* at midseason and harvest in fruit samples taken from the various treatment plots at the Kernan study site, as well as from other comparison plots.

Results and Discussion

Season-Long Releases of Partially Sterile Codling Moths. The Kernan site continued to be managed conventionally for all other pests in 1998. Even though the owner of this orchard had agreed to not treat our experimental release plots for codling moth, one azinphosmethyl cover spray was accidentally applied on 12 May 1998. An additional azinphosmethyl cover spray was applied to areas outside our release blocks on 18 May 1998.

Our analysis of midseason fruit sampling at the Kernan site revealed low fruit damage with no significant differences between the mean percent damage to apples collected from plots receiving 100 or 250 Gy treated codling moths or those taken from the inside control plots (Fig. 1). Similarly, at harvest, the mean percentage of apples damaged in treated plots continued to be extremely low and was found to be equal for both treatments (100 and 250 Gy). Tree banding failed to detect the presence of cocooning larvae in either treatment or inside control plots. While the mean percentage of apples damaged in treated plots (0.027%) was lower than the percent damage obtained for the inside control (0.04%), as well as that found in the original CAMP site (0.061%), these differences were not statistically significant. However, when the mean percent damage for these four treatments was compared with that found in CAMP 98 expansion site orchards (0.53%), the difference was found to be statistically significant ($\chi^2 = 15.9$, df = 4, $P = 0.0032$). Finally, when mean percent damage at harvest for all treatment and comparison blocks was analyzed, a highly significant ($\chi^2 = 22.8$, df = 6, $P = 0.0009$) treatment effect was found (Fig. 1). The percent fruit damage at harvest for both the outside control (0.70%) and the CAMP control blocks (2.02%) was greater than that detected at any of the other treatment locations.

Releases of Partially Sterile Codling Moths in Combination with Mating Disruption. No significant differences between treatments in the mean percentage damage to apples at midseason were detected at the Gold Hill site (Fig. 2). Similarly, at harvest, the mean

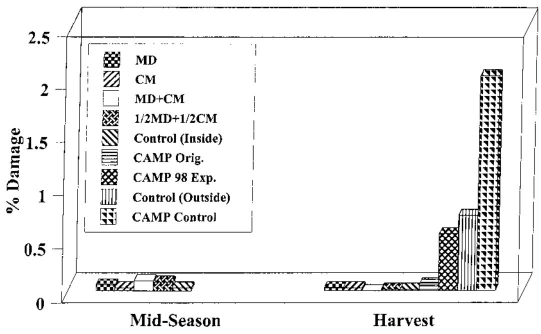

Fig. 2. Percent damage by codling moth, *Cydia pomonella*, at midseason and harvest in fruit samples taken from the various treatment plots at the Gold Hill study site, as well as from other comparison plots.

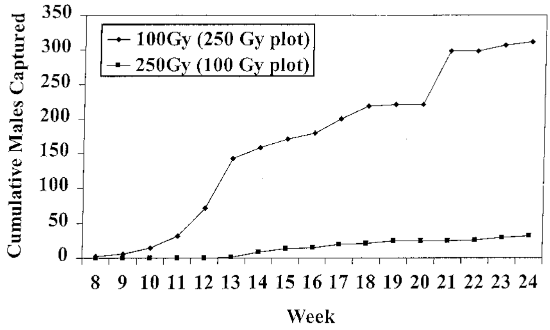

Fig. 3. Cumulative number of male codling moths, *Cydia pomonella*, treated with 100 and 250 Gy, that were recaptured in *opposite treatment release plots* (i.e., the number of 100 Gy treated moths that were recaptured in the 250 Gy treated plots and vice versa) at the Kernan study site.

percentage damage to apples for treatments A–D (MD, CM, MD+CM, ½MD + ½CM) and the inside controls were not significantly different. All damage figures were extremely low and ranged between 0.00% and 0.067% in samples of 7,500 whole fruit per treatment. Again, tree banding failed to detect the presence of cocooning larvae. A significant ($\chi^2 = 11.8$, df = 5, $P = 0.0375$) treatment effect was found when the mean percent damage for treatments A-D was compared with that for the outside control (0.70%). A comparison of the mean percent damage for treatments C (MD+CM) and D (½MD+½CM) (0.00% and 0.013%, respectively), the original CAMP site (0.061%) and the 98 CAMP expansion site (0.53%) at harvest revealed a highly significant ($\chi^2 = 17.33$, df = 3, $P = 0.0006$) treatment effect. Finally, damage found in all above-mentioned treatments (treatments. A-D, inside control, original CAMP and 98 CAMP expansion) was found to be significantly ($\chi^2 = 26.77$, df = 8, $P = 0.0008$) lower than the mean percent damage for the CAMP site control blocks (2.02%) at harvest.

In both experiments where we examined the use of partially sterile males, alone and in combination with mating disruption to control wild populations of codling moth, we found no significant differences in fruit damage between any of our treatments at any time of year. In addition, no statistical differences were detected in harvest fruit damage samples taken from the treated plots and the inside control plots. There may be two reasons why no such differences were detected. One possibility is that treatment effects were masked or concealed by the movement of (and control provided by) the released moths. For example, at the Kernan site where we compared the effect of moths treated with 100 and 250 Gy, we found that the moths treated with 100 Gy drifted into the 250 Gy release plots at a much higher rate than 250 Gy treated males entered the 100 Gy release sites (Fig. 3). Similarly, at the Gold Hill site there were no significant differences in the recapture of moths (in 10-mg baited traps) in the three treatments that received mating disruption (treatments A, C, and D) (Table 2). However, significantly ($F = 4.15$; df = 3, 8; $P = 0.0477$) fewer moths were recaptured in plots that included mating disruption than in plots without mating disruption (treatment B). This suggests the effect of mating disruption remained within each test plot while the effect of the released moths did not. The fact that the 100 Gy-treated moths dispersed beyond the various treatment plots in which they were released could have lowered damage levels in the plots receiving mating disruption.

The movement of the partially sterile moths also could have influenced results in our inside control plots for both study sites. In addition, to receiving additional azinphosmethyl sprays, significant numbers of treated moths were caught in these plots. For example, by week 11 at the Kernan site nearly as many 100 Gy moths were being caught in the control plots (average 63 moths/trap) as were being caught in the 100 Gy release plots (average 72 moths/trap). Clearly, the distance between plots receiving partially sterile moths needs to be much greater than the distances used in these experiments. Our data would suggest that if tree plantings are contiguous, a distance of at least 500 m is needed.

A second possibility for the lack of significance in our treatments is that the level of control in all cases was nearly 100%. From an experimental point of view, it would have been better had the mean percent damage of apples been ≈50% for one of the treatments. In this way, our opportunity to observe differences be-

Table 2. A comparison of *cydia pomonella* (CM) trap (10 mg) captures in plots receiving various combinations of mating disruption and 100 Gy-treated moths at the Gold Hill study site in 1998

Treatment	No. of Moths Captured (mean ± SD)
A − MD	348.3 ± 333b
B − CM	827.0 ± 175a
C − MD + CM	360.0 ± 72b
D − ½MD + ½CM	316.0 ± 158b

Means followed by the same letter are not significantly different, Waller-Duncan K-ratio, $P < 0.05$ (PROC GLM, SAS Institute 1989).

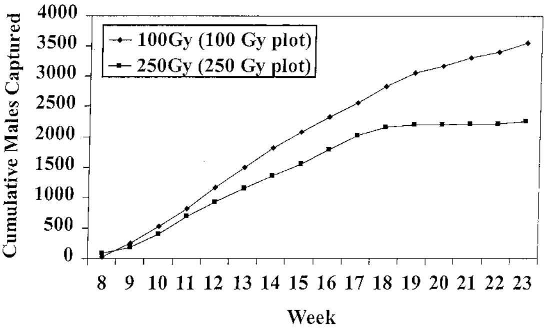

Fig. 4. Cumulative number of male codling moths, *Cydia pomonella,* treated with 100 and 250 Gy, that were recaptured in their *respective release plots* at the Kernan study site.

tween treatments would have been maximized. Nevertheless, from a pragmatic point of view, it is difficult to complain when all treatments provided almost complete control. At the Kernan site, fruit damage at harvest decreased from 1–2% in 1997 (S.B., unpublished data), when four sprays of azinphosmethyl were used (S. B., unpublished data), to <0.1% codling moth damage with a single application of azinphosmethyl and twice per week releases of partially sterile moths. It should be noted as well, that the one cover spray that was applied to our release plots in 1998 was the result of miscommunication between the orchard owner and his spray crew and not because trapping or damage results indicated it was necessary. At the Gold Hill site, fruit damage at harvest varied between 0.5–1.0% in 1997 with two azinphosmethyl applications (S. B., unpublished data), but decreased to <0.1% in 1998 with a combination of mating disruption and twice weekly releases of partially sterile moths with no application of azinphosmethyl.

Trap captures from the comparison of 100 and 250 Gy-treated moths at the Kernan site indicated that the moths treated at the lower dose of radiation were more active and dispersed greater distances. Not only were higher numbers of 100 Gy-treated moths captured than 250 Gy-treated moths in the plots in which they were released (Fig. 4), but significantly more 100 Gy-treated moths were captured in the 250 Gy release plots than were 250 Gy-treated moths caught in the 100 Gy plots (Fig. 3). The greater activity and competitiveness of the moths treated with 100 Gy may explain why significantly less fruit damage was observed in our Gold Hill experimental plots than was found in CAMP 98 expansion sites, which used 250 Gy-treated moths, despite similar population pressures and tactics employed. Our results were also more encouraging than those reported by the Sterile Insect Release Program in British Columbia, Canada (Bloem and Bloem 2000) using 250–330 Gy-treated moths. An additional explanation for the better and more rapid control achieved in these experiments than was reported by CAMP or SIR could be that greater care was taken to deliver the control tactics in our experiments, both in terms of handling and releasing the moths as well as in the placement of mating disruption dispensers, than was realized in these area-wide management programs. In either case, our results indicate that the release of partially sterile moths can be a very effective control tactic and continue to support earlier findings that suggest that the use of lower doses of radiation and partially sterile codling moths is more effective than the use of more fully sterile moths (Proverbs et al. 1978, Bloem et al. 1999b).

Our results also add to the mounting body of evidence that fears of increased fruit injury resulting from F_1 larvae are ill founded (Proverbs et al. 1978, Anisimov 1993, Bloem et al. 1999a). In these experiments, despite moderate codling moth pressure (peak of 2.6 wild moths/trap/week on 9 May, 2000 at the Kernan site) and twice per week releases of partially sterile moths (males 50% sterile, females 100% sterile) throughout the growing season, essentially no codling moth fruit damage was observed at harvest. In fact, every experiment conducted to date that we are aware of that has examined the use of fully sterile versus partially sterile moths for controlling wild codling moth populations supports the use of inherited sterility. As such, we recommend that all future efforts involving sterile insect release for codling moth control take advantage of the benefits provided by using lower doses of radiation. For example, the SIR Program in British Columbia, Canada began releases in 1994 using moths treated with 330 Gy. The SIR Program reduced the level of radiation to 320 Gy in 1995 and 1996, and then to 250 Gy in 1997 and following years (Lorne Tomlin, personal communication). Our research indicates that further reductions in the sterilizing dose of radiation to as low as 100 Gy should improve the competitiveness of and control provided by the released moths. As an additional programmatic bonus, irradiating codling moths with a lower dose of radiation would reduce the person-hour cost to irradiate moths, increase the number of moths that could be irradiated per day and reduce costs by extending the useful life of the Co^{60} irradiator.

With recent announcements under the Food Quality Protection Act about further restrictions on the use of azinphosmethyl and other organophosphate insecticides, apple growers continue to look for cost-effective methods of controlling the codling moth. The use of mating disruption on an area-wide basis, as demonstrated by the USDA-ARS CAMP, has given very positive results. We feel that inherited sterility is another tactic that warrants continued evaluation and support. Results from the Lake Osoyoos CAMP site suggest that combining mating disruption with sterile moth releases provides an added measure of control. Results from the experiments presented here suggest that the use of partially sterile moths can be an effective stand-alone tactic and that it may allow for lower dispenser rates or moth release rates when combined with mating disruption. The use of the sterile insect technique for controlling and even eradicating insects such as the screwworm fly and the Mediterranean fruit fly is now almost routine. The increased effectiveness afforded by partially sterile versus fully sterile moths offers hope that the use of inherited sterility may provide similar results for the control of lepidopteran pests.

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